INTERNATIONAL JOURNAL OF MECHANICAL ENGINEERING AND TECHNOLOGY (IJMET)

ISSN 0976 – 6340 (Print)
ISSN 0976 – 6359 (Online)
Volume 6, Issue 5, May (2015), pp. 34-40
© IAEME: www.iaeme.com/IJMET.asp
Journal Impact Factor (2015): 8.8293 (Calculated by GISI)
www.jifactor.com

IJMET

©IAEME

EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION OF LOW COST STANDING WAVE THERMOACOUSTIC REFRIGERATION

Ravindra Edlabadkar[1] **Shankar kadam**[2] **Dhnyanesh Kumbhar**[3] **Dr. Satish Kadam**[4]

[1]M.Tech.Student, Mechanical Engineering Department, BVCOE, Pune, India

[2]M.Tech.Scholar, Mechanical Engineering Department, BVCOE, Pune, India

[3,4]Associate Professor, Mechanical Engineering Department, BVCOE, Pune, India

ABSTRACT

All conventional refrigeration and air conditioning use environmentally sensitive refrigerants. The HCFC's or HFC's may lead to higher global warming than CO_2. Thermoacoustic Refrigeration (TAR) is an option and deals with thermodynamics, fluid dynamics and acoustics. TAR operates with inert fluids, no frictional losses and less maintenance cost. The development of low cost standing-wave thermoacoustic refrigerator has been undertaken by many researchers.

This paper presents experimental study of low cost glass stack TAR with stack material and stack position as parameters of study. An experimental setup for experimentation and validation of numerical analysis is developed. Experimentally, maximum temperature of 11K for Glass fibres with glass capillary tube spacers kept at 0.15m position from speaker inlet in glass resonator of 0.02m diameter and 0.242 m length, with air as fluid medium, with acoustic sine wave frequency of 350 Hz and amplitude 10 kPa is obtained.

Numerical analysis of capillary glass tubes stack with stack and resonator dimensions, stack position as well as boundary condition approximately same as the experimental conditions, is done as case study. CFD software, ICEM CFD 14.5 and Fluent 14.5 on ANSYS workbench 14.5 is used for the case study and results are presented here. Temperature difference of 6K is obtained. The experimental values and numerical values are in good agreement.

Keywords: Thermoacoustic refrigerator (TAR), Computational fluid Dynamics (CFD), Resonator, Glass Stack, Acoustic waves and frequency

1. INTRODUCTION

In thermoacoustic refrigeration, temperature difference across the porous thermoacoustic stack is generated by acoustic (sound) energy input, without any environmentally sensitive refrigerants or frictional losses. It does not need seals. It is simple in design. It facilitates analogue capacity control.

A typical TAR consists of a sound source attached to a close ended resonator tube filled with air as fluid medium. The resonator envelopes porous stack. Two heat exchangers are placed across the stack. The acoustic wave from the acoustic driver makes the fluid resonant. Thus oscillating standing acoustic wave is created. The stack is placed between pressure antinode and velocity antinode of the acoustic wave. A temperature difference across the length of the stack occurs because of compression and expansion of the fluid. The heat exchange takes place between fluid and the stack. The heat exchangers exchange heat with the surroundings at the cold and hot sides of the stack. The stack material should have low thermal conductivity and higher heat capacity than fluid. Thus it allows steady thermal gradient across the stack walls. The stack and resonator material should have strength to withstand higher pressure. Resonator tube should have low thermal conductivity to prevent heat leakage.

Syeda Humaira Tasnim and Roydon Andrew Fraser [1] studied the effect of stack position on magnitude of cooling. R.C. Dhuley and M.D Atrey [2] investigated effect of fluid pressure on stack end temperatures. B.V. Kamble et.al.[3] has optimized the design parameters for thermoacoustic engine. Mehta S. et.al [4] investigated improvement of standing wave (SW) TAR by acoustic amplifier. Mehta S. et. al. designed and developed SW TAR for 300 Hz. Kartik M. Trivedi [5] studied the temperature gradient in the context of stack positionng. Experiments were conducted by Giulio Allesina [6] varying the stack material, Stack geometry to analyze the performance of thermoacoustic refrigerator. Mathew Skaria et.al.[6] modeled TAR with different fluids using CFD.

The literature reviewed reveals the investigations pertaining to performance improvements of thermoacoustic refrigerator. The authors came across no literature that specifies design of low cost TAR with glass and glass wool stack. Therefore, the present study aims to carry experimental study of low cost TAR with stack material, stack position and frequency as parameters of study. Also numerical case study is undertaken for acoustic sine wave frequency of 350 Hz and amplitude of 10000 Pa.

2. EXPERIMENTAL SETUP

Figure 1 shows a schematic diagram of the low cost thermoacoustic refrigerator. It consists of an acoustic driver (speaker) which is connected to the resonator through a diverging conical adiabatic member (funnel). The stack is placed at appropriate position inside the resonator with two thermocouples across it for temperature measurement.

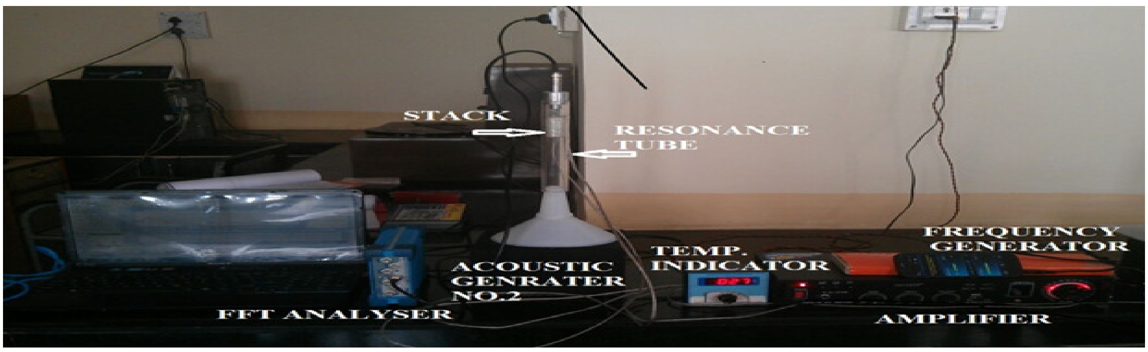

Fig. 1: Experimental set up for low cost TAR

These stacks forms different configurations and are made from Glass capillary tubes, Glass fibre with capillary spacers and Glass fibre with Nylon spacers. The capillary tubes and spacers are rolled into a bundle with outside diameter just abutting to inside diameter of the Glass resonator tube. The various configurations pertaining to stack material, stack position, frequency and type of acoustic wave are given in the table. Calibrated K type thermocouples and Digital Temperature Indicator are used to measure temperature at hot and cold end of the stack as well as atmospheric temperature. Electrical power input to the speaker is measured using calibrated Ammeter and Voltmeter. The standard frequency generator is put to use and the pressure variations in the resonator tube at appropriate locations are measured using Pressure transducers.

2.1 Stack

The stack is used to exchange heat with the fluid, The amount of acoustic power that can be exchanged as heat depends on certain features of the stack viz. material properties, dimensions and the position in the resonator. Figure 2 and Figure 3 (a,b and c) show the stacks. The stack material should have a high heat capacity and low thermal conductivity along resonator axis. The length is important for the temperature gradient. The length and cross-sectional area of the stack determine how much the sound waves are intercepted.

Fig. 2 Rolled Stack

2.2 Working Fluid

High mean fluid pressure, a high velocity of sound and a large cross-sectional area gives more thermo acoustic power. Hence generally, helium is used in thermo acoustic devices. But from low cost perspective, air at atmospheric pressure with low Prandlt number and low viscous losses is used as the working fluid.

2.3 Resonance Tube

The shape, length, weight and the losses are significant parameters in resonator design. Length of resonator is determined by the resonance frequency and minimal losses at the wall of the resonator. The length of resonator tube corresponds to quarter of the wavelength of the standing wave [1]:

Length of resonance tube,

$$L = v/4f \quad (1)$$

Where, Velocity of sound in air, v =340 m/s
Frequency of Sound wave, F=350
L= 340/(4*350)
= 0.242 m

Where, a is the speed of sound, L is the length and F is the resonance frequency. For the resonance frequency 350Hz, the length of resonant tube is set equal to 242 mm that corresponds to the quarter wavelength of the acoustic standing wave, the diameter of the resonator tube is set equal to 20mm. The acoustic resonator comprises of a straight acrylic tube of length 242 mm with internal diameter 20 mm and the thickness of the wall, 2.5mm. One end of the tube is attached to the small end of acrylic conical flask. At the other end of the resonator, an aluminum plug is placed which works as reflector wall and heat exchanger.

2.4 Acoustic Generator

In SW TAR, high mean fluid pressure, a high velocity of sound and a large cross-sectional area gives more thermo acoustic power. Hence generally, helium is used in thermo acoustic devices. But from low cost perspective, air at atmospheric pressure with low Prandtl number and low viscous losses is used as the working fluid.

Fig. 3 Resonator a top the

Fig. 4 FFT Analyzer for Pressure Measurment

2.5 Instrumentation

Different process parameters viz. pressure, temperature, amperage, voltage are measured using calibrated instrumentation. The locations of measurements are selected judiciously and appropriately.

The pressure wave amplitude is measured using pressure transducer and FFT analyzer. Calibrated K type thermocouples and calibrated digital temperature indicator are used to measure temperature of hot and cold end of the stack as well as atmospheric temperature. Electrical input to speaker is measured using calibrated 0-20 A, 600V Multimeter.

3. EXPERIMENTATION AND RESULTS

Extensive experiments are conducted on the set up with the configurations given in the table no.1

Table No.1: Scope of Experimentation

Parameters	Configurations		
Frequency	350 Hz		
Stack position	0.1m		0.15m
Stack Material	Glass Capillary tubes	Glass fibres with nylon spacers	Glass fibres with glass capillary tube spacers

The speaker (acoustic driver) is given the acoustic input generated by the frequency generator through amplifier. The power input is measured using Ammeter and Voltmeter. The K type calibrated thermocouples are placed in close proximity of the either ends of the stack. They are connected to the temperature indicator. Pressure transducer probe is inserted through the small aperture of the aluminium plug, measures the amplitude of the pressure wave. The set up is put on and run for about 30 minutes before the readings are taken to ensure that parameters stabilize. The readings are recorded as given in the table no.2.

Thus it is observed that maximum temperature difference corresponds to Glass fibres with glass capillary tube spacers' configuration and 0.15 m stack position.

Table 2 Observation Table

Stack Material	Stack Position	
	0.1 m	0.15m
	Temperature Difference (Stack Inlet & Stack Outlet, K)	
Glass Capillary Tubes	04	6.5
Glass fibres with nylon spacers	03	06
Glass fibres with glass capillary tube spacers	05	11

4. NUMERICAL ANALYSIS

Numerical analysis leads to better understanding of the physics. It reveals fluid behaviour which otherwise difficult to know experimentally. The thermodynamic processes in TAR are described using the conservation of mass, momentum and energy equations in the backend of the CFD simulations.

4.1 Computational Grid Generation

The domain of the solid stack and fluid is descritized into small 2D elements over which mass, momentum and energy equations are solved. The regions near acoustic driver inlet area, stack inlet, stack outlet and reflector wall, experience steep pressure gradients. Hence the mesh size is kept small (fine grid) in these regions. The meshed model is shown in figure 8. The grid quality is checked for skewness, aspect ratio etc. The grid is refined periodically to seek grid independent solution and higher numerical accuracy.

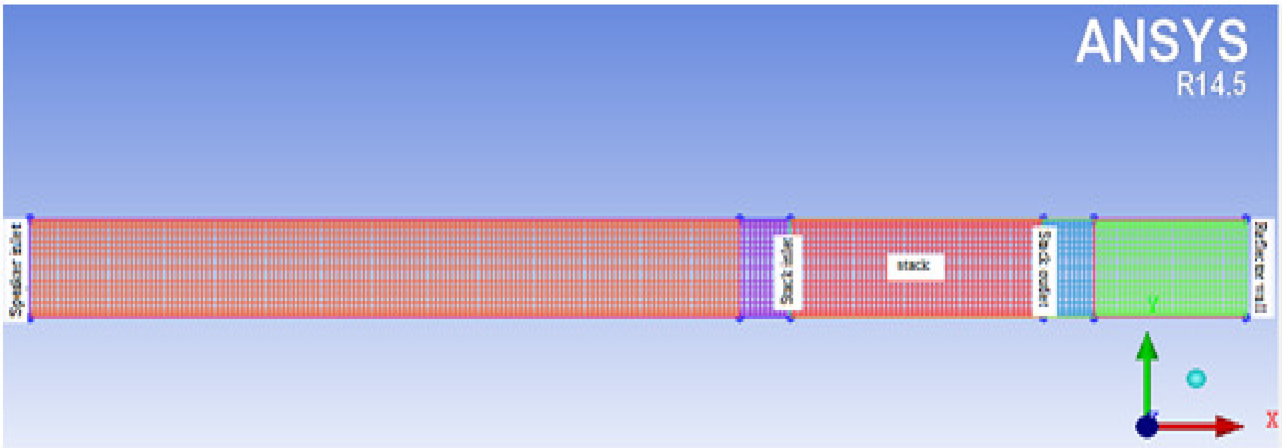

Fig. 5 Meshed Model

4.2 Computational boundary Condition

The leftmost edge of the model represents speaker inlet. To simulate pressure wave input, this boundary is defined as pressure inlet. An User Defined Function (UDF) code is written and incorporated as pressure input. This UDF takes into account the amplitude and frequency of the sound wave as supplied at actual through speaker to the resonator input during experimentation. The porous stack with porosity 0.7 is drawn in the model with fluid domains being sandwiched between two abutting solid stack domains. The resonator walls are given adiabatic wall boundary condition. The aluminium plug in the experimentation is represented by reflector wall in the model.

4.3 Computational Parameters

An unsteady state, viscous, realizable, two equation k-ε model is selected. Energy equation is put on and standard wall function is selected as the physics of the model. Appropriate reference values viz. Area, length, depth etc. are selected as per the geometry of the experimental set up. PISO Pressure-velocity coupling scheme and PRESTO spatial discretization for pressure has been employed**.**

4.4 Computational Results

For validation of the numerical analysis, the experimental results are compared with computational analysis results. they are found in good agreement (within 10%). Results are obtained in terms of the temperature plots and pressure plots in close proximity of stack inlet and stack outlet.

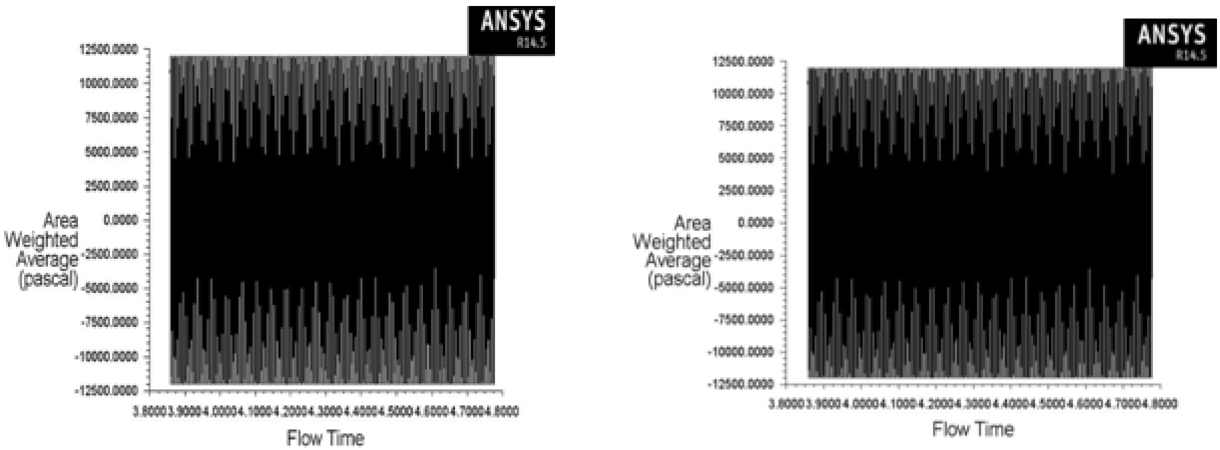

Figure 6 Pressure Variation Near Stack

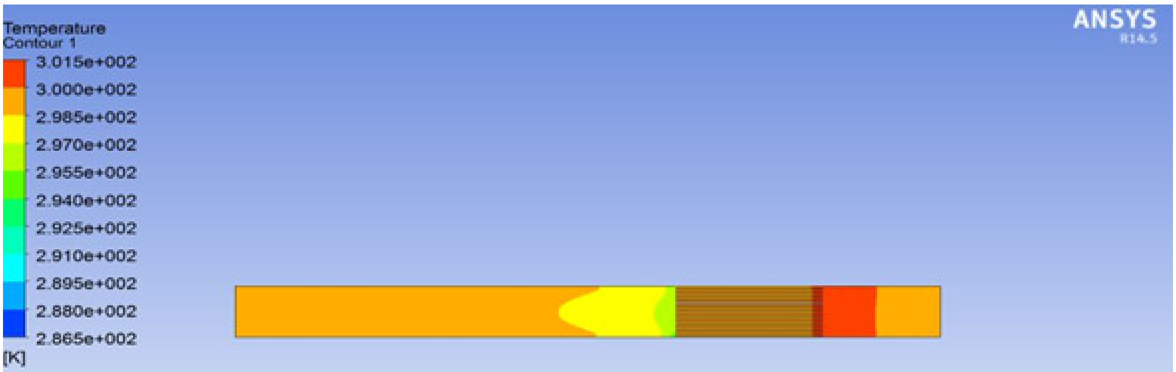

Fig. 7 Temperature Contour Across the Resonator Tube Fluid and Stack Solid Domain

5. CONCLUSION

In this paper, the results of experimental investigation and numerical analysis as a case study are presented. An experimental setup for validation and experimentation is developed. Based on acoustic frequency as input, resonator length and location of the stack inlet are theoretically decided and experimentally confirmed. In the considered set of stack configurations, experimentally, Glass fibres with glass capillary tube spacers gives highest temperature gradient with temperature difference of 11 K at 0.15 m position from speaker inlet.

A case study of Glass Capillary Tubes, for numerical analysis is undertaken, to better understand the physics. The experimental values are used for validation of numerical results. Both the values are found in good agreement. Temperature difference of 6K is obtained across glass capillary stack kept at 0.15 m position from speaker inlet, with dimensions of stack and resonator as well as boundary conditions approximately same as the experimental set up.

REFERENCES

[1] Syeda Humaira Tasnim and Roydon Andrew Fraser (2010), “Thermal Field Measurements of a Thermoacoustically Driven Thermoacoustic Refrigerator” ASME Journal of Thermal Science and Engineering Applications, vol. No.2,pp. 021010-1 to 021010-10.

[2] R. C. Dhuley and M.D. Atrey (2011), "Cooldown Measurements in a Standing Wave Thermoacoustic Refrigerator", Indian Journal of Cryogenics, Vol.36, No.1-4, pp. 158-163.

[3] B. V. Kamble, B. T. Kuzhiveli, S. Kasthurirengan, Upendra Behera, K.V.Dinesh, Geeta Sen, M. V. N. Prasad (2011) "Performance characterization by Optimized Design of Thermoacoustic Prime Mover", Indian Journal of Cryogenics, Vol.36, No.1-4, pp. 37-41.

[4] Mehta S., Desai K., Naik H., Atrey M. (2013), " Investigations on performance improvement of standing wave type thermoacoustic prime mover using acoustic amplifier", Indian Journal of Cryogenics, Vol.38, No.1-4, pp.184-189.

[5] Kartik M. Trivedi (2014), “Effect of Stack Positioning on a Temperature Difference of Thermoacoustic Refrigerator”, Indian Journal of Research, Vol.3, Issue 5, pp. 93-95.

[6] Giulio Allesina (2014), “An experimental analysis of a stand-alone standing-wave thermoacoustic refrigerator”, International Journal of Energy and Environmental Engineering, Vol. 5/1/4, pp. 2-9.

[7] Mr.Anirban Sur, Dr.Randip.K.Das, “Review on Solar Adsorption Refrigeration Cycle” International Journal of Mechanical Engineering & Technology (IJMET), Volume 1, Issue 1, 2010, pp. 190 - 226, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.